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ANALYSIS OF RECTANGULAR-SHAPED COLLAR CONNECTORS FOR COMPOSITE TIMBER-STEEL-CONCRETE FLOORS: PUSH-OUT TESTS

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Abstract. The paper deals with the experimental analysis of an innovative connection system for composite timber-steel-concrete floors. The connection device consists of a collar composed by two or more parts, astride the timber beam, bolted together at adjacent wings. A rubber layer is interposed at the collar-beam interface. The slipping action transmission is guaranteed by the superior wings of the collar or by a steel stud, purposely welded to the collar in the upper part, which are immersed in the concrete cast. In this paper push-out monotonic tests on several rectangular-shaped configurations of the connection system are presented, being part of a more comprehensive experimental campaign, aimed at the system performance evaluation and optimization. First, the preliminary numerical analyses, meant to define both the best geometrical characteristics of the specimens and the configuration of the testing apparatus, are illustrated. Then the push-out tests, considering subsequent improvements of the connection system are detailed. The connection behaviour is discussed in terms of force-slip relationship.

Keywords: composite timber-concrete-floor, collar connector, push-out monotonic tests.

1. Introduction

Ancient masonry buildings are widely spread in all the European countries. In such constructions floor structures are typically made of a primary layout of timber beams with circular or rectangular cross-section, supporting a secondary one, which an inert mortar slab is cast on.

In the framework of the restoration of ancient constructions, the timber–concrete composite system represents a reliable solution for the upgrading of the existing floor slabs (Piazza, Turrini 1983; Giurani 2002; Mungwa *et al.* 1999), either in case of old beams have both inadequate strength and stiffness, with consequent unacceptable deformations, or in case of the beam floor does not accomplish the function of a rigid diaphragm in its plane when the building is subjected to horizontal forces; moreover, it allows to improve both acoustic and thermal floor performances, together with the fire resistance.

The intervention generally consists of a concrete thin slab connected to the timber beams by means of dry connectors, like screws, nails and studs, which should be inserted into holes requiring to drill the existing timber members. In such composite systems the timber beam resists the tensile forces, the concrete slab withstands the compressive forces, generated by bending, and the connectors absorb the slip actions developed at the interface between the slab and the beam. This technology is successfully used in many applications since the 1980s. In fact, it is characterized by a short time of construction and it does not require the removal of old floors, what allows the preservation of the integrity of historical painted ceilings, when they are present at the floor intrados.

The most commonly used techniques of joining concrete to timber are summarized in Fig. 1. They can be grouped as follows: (a) punctual connection devices such as nails, screws, studs and similar; (b) small metallic plates or nets located at constant spacing; (c) saw-tooth shaping of the beam and screws located at each indentation; (d) metallic trellis or mesh that realize a continuous connection device. All these systems are generally applied to new composite floor constructions. In Fig. 1 the connection devices are grouped in relation to their stiffness (Ceccotti 2002), the latter growing from group (a) to group (d) connections. The typical behaviour of such systems is well represented by the shear force (Q) vs slip (v) relationship obtained through push-out tests (Fig. 2).

The manufacturer companies propose several types of connection elements, each one adapted to specific design requirements, in order to reduce the building cost and make timber-concrete structures more widespread on the market.

As example, in Figs 3 and 4 some connection types belonging to the group (a) are illustrated. In Fig. 3 the device developed by the Tecnaria Company consists of a steel stud welded to a steel plate, which is, in turn, connected to the timber beam by means of two screws. Some results of the related experimental campaign carried out

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at the University of Trieste (Fragiacomo *et al.* 2000) with reference to the steel connectors are drawn in terms of load (F)-displacement (v) curves. The tests were performed up to collapse, corresponding to the extraction of the screws from the beams. In Fig. 4 three different types of shear connectors developed by the Hilti Company are presented (Mungwa *et al.* 1999) and the results of push-out tests carried out are also shown. They are: (A) a flexible connector, which is commonly used to connect concrete slabs to steel beams, namely, Hilti HVB connector; (B) a tubular connector, with a drilled head, where the holes are filled by mortar in the timber–concrete connection systems, namely Hilti Tubular connector; (C) a hollow cylinder with varying cross-section size and wall thickness in the part which penetrates into the wooden matrix, made of galvanized heat-treated anti-corrosion steel, namely, INSA-Hilti connector. As shown in Fig. 4, the type B connection system exhibited the largest shear capacity, while the type C one the largest ductility.

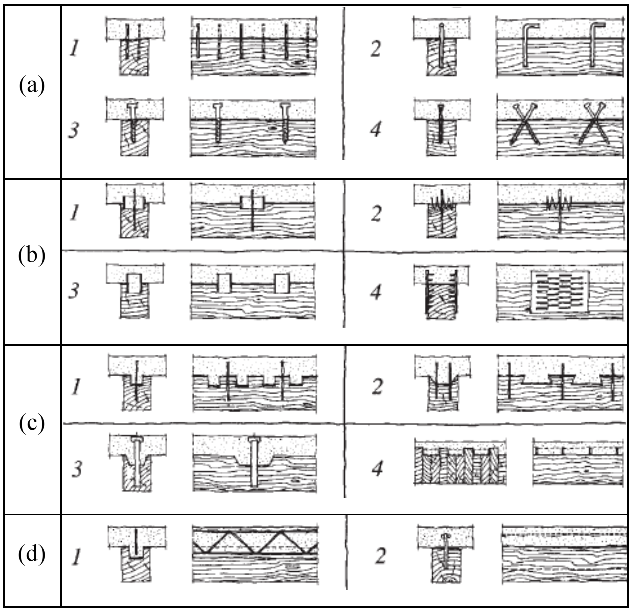


Fig. 1. The most common concrete-timber connections (Ceccotti 2002)

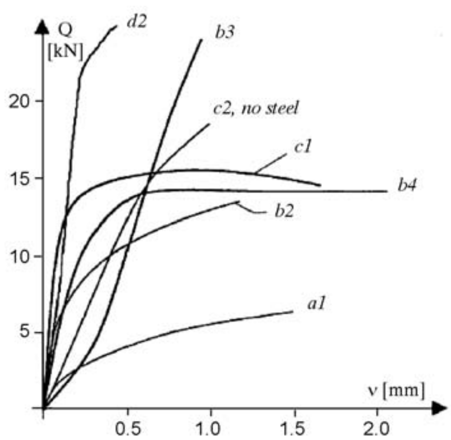


Fig. 2. Typical load-slip behaviour of connectors (Ceccotti 2002)

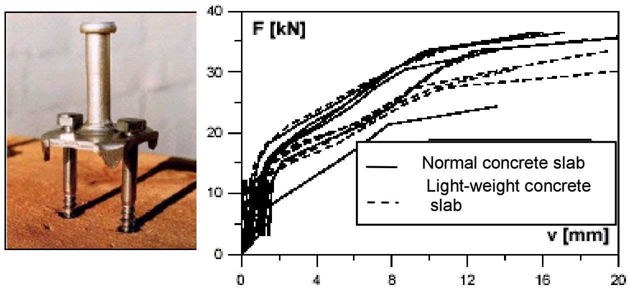


Fig. 3. The connection system by Tecnaria (Fragiacomo *et al.* 2000)

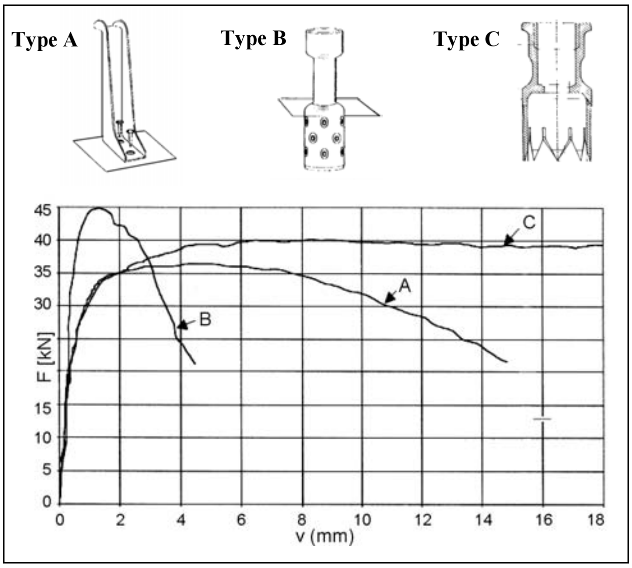


Fig. 4. The connection systems by Hilti (Mungwa *et al.* 1999)

A connection system that can be inserted within the group (c) is the notched shear key/anchor connector, which was initially developed by Natterer *et al.* (1996). It consists of a steel dowel glued into a tapped pilot hole in the wood by an adhesive (Gutkowski *et al.* 2008). Within the concrete layer a plastic sleeve is located around the shank of the dowel. After the concrete cures, the dowel is tightened to realize the connection. The void at the connector location in the slab is grouted for protection against moisture and fire. The slip force transmission between the concrete and the timber layers occurs by shear through the concrete indentation; while the tensioned dowel keeps the magnitude of the interlayer slip low, but it does not transfer shear. The typical bending behaviour, in terms of load-mid span deflection of the overall composite system, is plotted in Fig. 5.

Another connection type, which belongs to the group (d) or to the group (b), if it is continuous or discontinuous respectively, is the HBV-System (Bathon, Graf 2000). It consists of a steel mesh glued to the timber beam on one half and immersed into the concrete slab on the other one (Fig. 6). This system provides a connection between timber and concrete that is stiff in the elastic range and ductile in the plastic one. In Fig. 6 the HBV system is compared to other types of shear connector in terms of load-displacement curves (Bathon, Clouston 2004).

It is worth noticing that all the above described connection systems provide the drilling of the timber beam. Actually they are conceived for new wooden elements. In case of ancient timber beams the presence of ring shakes, slots, cracks, generally induces a reduction of the resistant cross-section on an existing member, whose current mechanical properties are difficult to be determined on site. Therefore, in order to avoid any strength reduction that could be certainly caused by the perforations for the installation of traditional connectors, an innovative type of connection, which basically consists of steel collars, surrounding the wooden stock, equipped with connectors (Mazzolani *et al.* 2005) is conceived. This kind of device meets a high level of reversibility requirements.

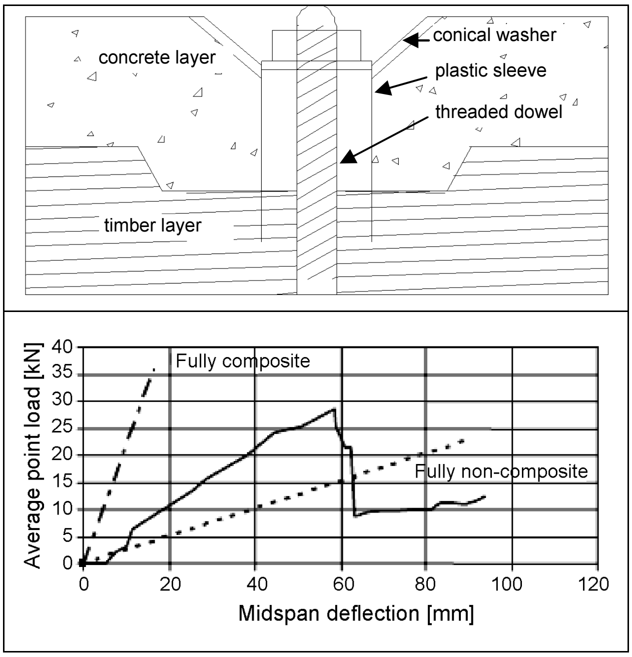


Fig. 5. The notched shear key/anchor connection (Natterer *et al.* 1996)

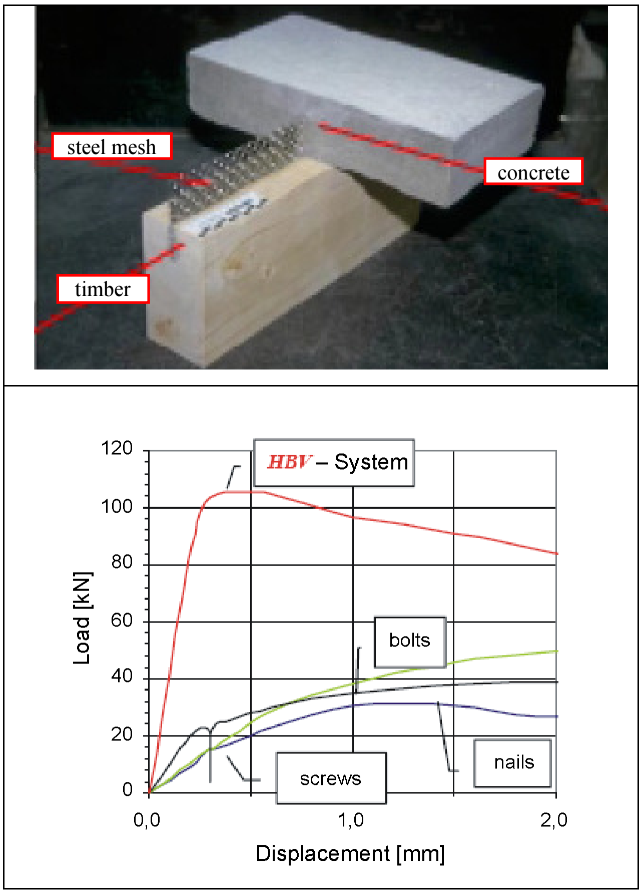


Fig. 6. The continuous HBV-System (Bathon, Clouston 2004)

An experimental campaign on full-scale specimens of the collar connectors is developing at the DECIVIL (Department of Civil Engineering and Architecture) of the Superior Technical Institute in Lisbon (Prof. L. Calado coordinator; Esposito 2006), with the collaboration of the DIST (Department of Structural Engineering) of the University of Naples "Federico II" (Prof. F. M. Mazzolani coordinator). The research activities have started in the framework of the international research project PROHITECH (Earthquake Protection of Historical Buildings by Reversible Mixed Technology).

The experimental investigation includes both monotonic and cyclic push-out tests on single connection devices and both monotonic and cyclic bending tests on composite timber-concrete beams, equipped with the collar connectors. The purpose of the experimental campaign is the performance evaluation, in terms of both strength and stiffness, of the system in view of its optimization. The experimental tests were set up on the basis of preliminary numerical simulations of push out tests on several configurations of the system obtained by varying the main parameters that affect the behaviour, such as number of steel parts, both width and thickness of collars and preloading forces in the bolts. As a consequence, the device supplying the better behaviour was realized to perform the monotonic push-out experimental tests. What is more, during the progress of the experimental activities, several types of connectors, corresponding to further improvements of the system, were also studied. Subsequently, the planned cyclic push-out and bending tests were carried out on the systems whose experimental responses at the best approximated the theoretical reference of one of the ideal connections.

In this context the paper presents the first part of the whole experimental campaign, corresponding to the monotonic push-out tests on timber stocks with rectangular-shaped sections. In particular, first of all the main features of the tested device are depicted and the preliminary numerical investigations are illustrated. Therefore the push-out experimental tests are discussed, pointing out the progressively achieved enhancement of the connection detail and performance.

The system behaviour is presented in terms of force-slipping relationships.

2. Description of the system and design data

The steel connector system between the timber beam and the concrete slab consists of steel collars, placed astride the beam, which are composed by two or more parts, bolted together at appropriate folded wings; different configurations are therefore possible. The function of connector can be carried out by the couple of wings located at the superior edge of the beam (Fig. 7a) or by a traditional stud welded to the steel collar (Fig. 7b). At the interface between the steel collar and the timber beam, a rubber layer could be located in order to optimize the contact between elements, filling the gaps due to the surface irregularities of the wooden stock. The complete transmission of the slipping force through the connectors between the concrete slab and the timber beam is possible thanks to the bolt tightening that provides the necessary transversal ringing action, which guarantees the friction at the interfaces.

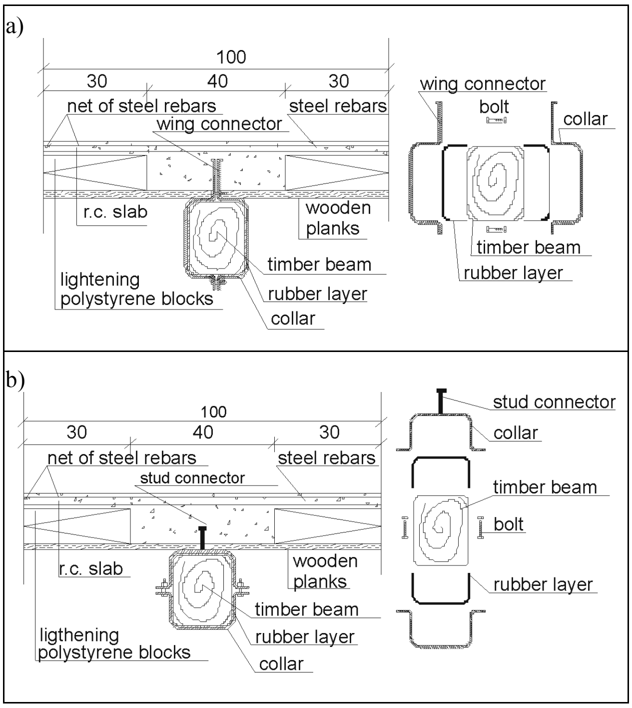


Fig. 7. The proposed innovative collar connection systems (cm): a) wing connector; b) stud connector

The design of the proposed connection system has been carried out by imposing the equivalence with the traditional stud connection system in terms of both strength and stiffness (Gelfi *et al.* 1998), by assuming the perfect adherence at the timber beam-rubber layer contact surface with a friction coefficient μ equal to 0.5 and the rubber layer as solidarized to the steel collars. In particular, with reference to the structural restoration intervention to an ancient historical timber floor (Faggiano *et al.* 2009), the design value of the shear force (F_0) to be transferred and the required stiffness (K_0) are equal to 24 kN and 55 N/mm^2, respectively.

Therefore, the total bolt tightening force, which assures the needed friction for the slipping resistance, should be $N_{0,t}$ = 48 kN.

As a result, the following design data are required:
– wing size 7×60 mm (thickness × width);
– steel grade S275;
– M8 class 5.6 bolts;
– traditional steel stud of 12 mm diameter, class 8.8;
– 50 cm spaced collar;
– rubber type SISMI 60, 5 mm thick.

3. Preliminary numerical analyses

3.1. General features

Preliminary to the experimental campaign, a numerical study was carried out, focusing on a single connection devices, with the aim to catch the main peculiarities of the system behaviour, which are useful to appropriately set up and control the experimental tests. Therefore, a refined finite element model of the collar system was set-up, by means of the ABAQUS non-linear numerical code (Hibbitt, Karlsson, Sorensen, Inc. 2004). Details of the preliminary numerical analyses can be found in Faggiano *et al.* (2009).

Several configurations of the steel collars were considered, in order to choose the optimal type to be used in the push-out tests.

The numerical investigation was articulated in 2 parts. The first one is the calibration of the material models, based on the results of existing experimental tests; in particular, bending tests, carried out on timber beams for evaluating both the elastic and shear modulus (Mazzolani *et al.* 2004), as well as tests in compression and shear on rubber bearings (Forni *et al.* 1993). The second part consists of push-out analyses of the systems. In this regard, the concrete slab was not modelled but only its full restraint effect on the steel connector was taken into account, in order to reduce the computational effort. In fact, the purpose of the study was to examine the behaviour of the connection device, focusing on the collar-beam interaction.

The three systems of configurations examined differ by the position of the wings, the number of collar parts and the connector type. The specimen geometrical characteristics are shown in Fig. 8, while in Fig. 9 the assembled FEM models are represented.

Concerning the contacts between adjacent components, the following interactions were modelled:

- Rubber-steel collar: a constraint that tightens the joints of the rubber layer, hindering any slipping.
- Rubber-timber beam: a surface-to-surface interaction, which is characterized by a tangential slipping among parts, with a friction coefficient equal to 0.50, and a normal behaviour that provides the transmission of any contact pressure between surfaces, when they are in contact.
- Collar wings: a surface-to-surface interaction, modelling the possible contacts between adjacent collar wings, which could be caused by tightening bolts; in this case a steel-steel friction coefficient equal to 0.30 is assumed.

With regard to the mesh of the models, according to a preliminary sensitivity study, 3 different discretisations, representing the best compromise between time spent for analysis and accuracy of the obtained results, were used along the longitudinal direction (Fig. 9). In particular, for the beam component the mesh is more accurate in the middle part, where the collar is applied, and the same mesh was adopted for the collar and the rubber layer models.

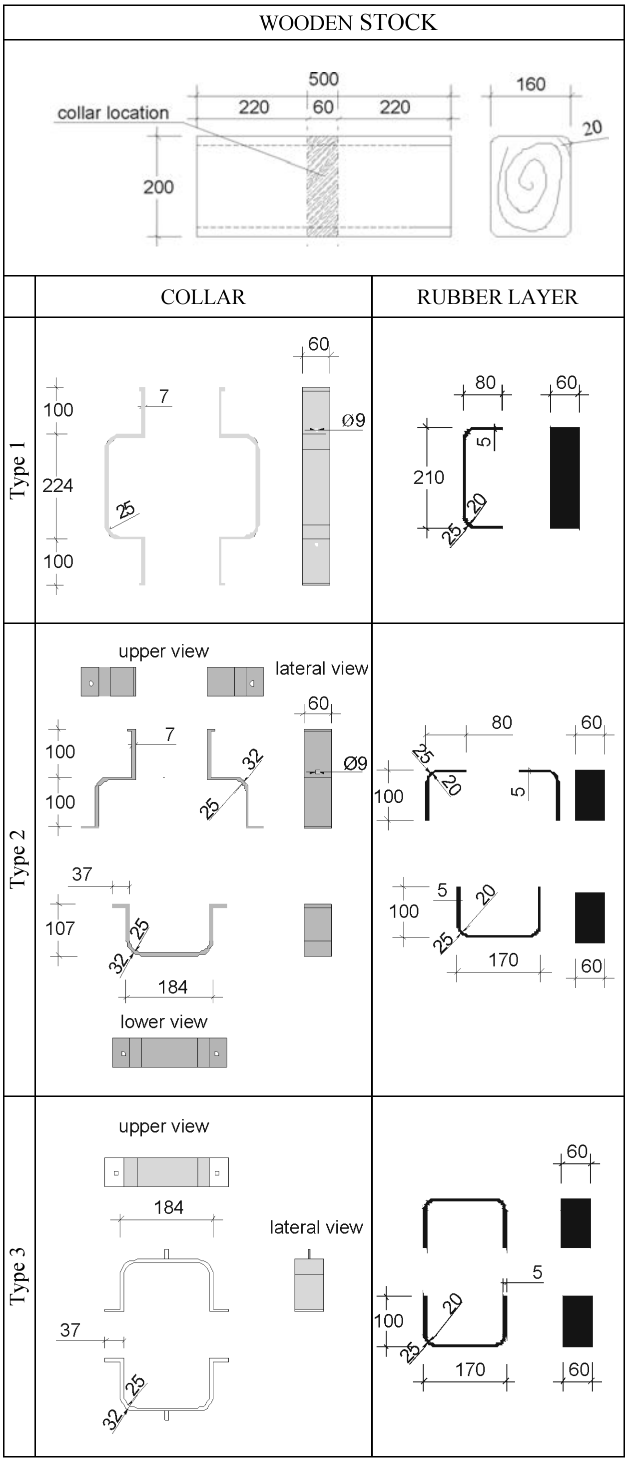


Fig. 8. Geometrical characteristics of the specimens (mm)

The load pattern was divided in 2 steps:

Step 1. The application of the preloading forces due to tightening bolts;

Step 2. The push-out loading condition, which was imposed by applying to the beam a distributed increasing pressure at one end surface.

The restraint conditions were defined accordingly. In particular, full restraints were applied to the timber beam at the step 1 and to the steel wings or stud at the step 2, in order to simulate the presence of the concrete slabs.

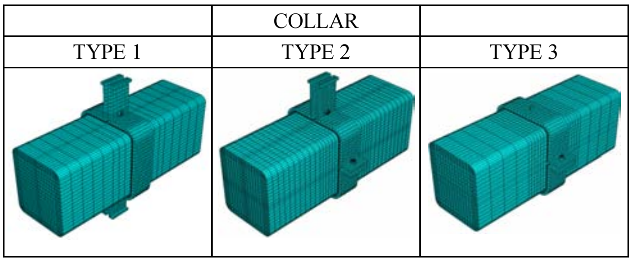


Fig. 9. FEM models of the analysed specimens

3.2. Numerical analyses results

During the analyses the following behaviour was observed (Fig. 10).

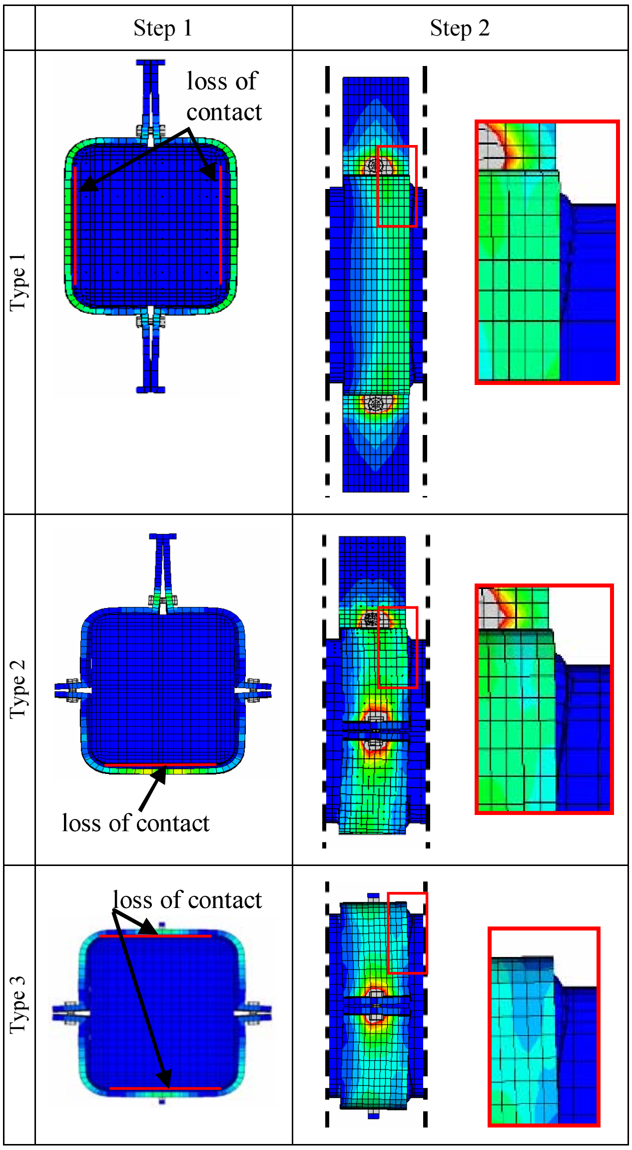


Fig. 10. Stress distribution in the deformed configuration of the connection system, at the bolt tightening (step 1) and at the system failure (step 2; N/mm^2)

When the bolt tightening is applied (step 1), a deformation of the collar occurs. In particular, the extremities of the superior and inferior couples of wings come in contact; on the contrary, a loss of contact between the rubber and the wooden elements in some parts of the adjacent surfaces takes place. During the push-out loading phase (step 2), the shear deformation of the rubber occurs (see Fig. 10), then a gradual reduction of the friction occurs at the contact surfaces up to the complete slipping.

The comparison between the responses of the three types of collars during the push-out tests is shown in Fig. 11, in terms of the applied force (F) and corresponding collar-beam slipping relationship. As a reference, the curve corresponding to the theoretical ideal behaviour of the designed connection system, is also given.

In Fig. 11 the ratio ($\overline{F}$) between the actual maximum applied force (F_{max}), which induces the complete slipping, and the maximum theoretical one (F_0) is reported. In all cases, the total tightening force ($N_{0,t}$) is 48 kN.

The exhibited worse behaviour of the three systems as respect to the theoretical one, in terms of both stiffness and strength can be ascribed to the fact that the actual contact area at the interface between the rubber and the timber beam is smaller than the ideal completely extended one due to the gaps developing at the bolts tightening.

The type 3 collar supplies the better behaviour, in terms of both strength and stiffness, the strength being about 100% and 50% larger than type 1 and type 2 collars, respectively, and stiffness similar to type 1 collar and lightly larger than type 2; moreover, it allows to substitute the rubber layer without any damage to the connector, the latter being apart from the bolted wing.

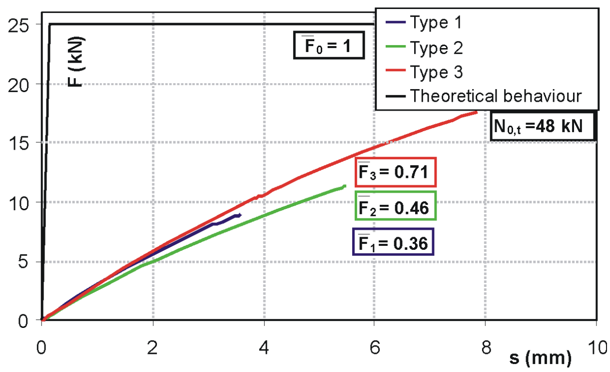


Fig. 11. Push-out test results: comparison between numerical responses for the examined connection systems

4. The push-out monotonic tests

4.1. Testing apparatus

On the basis of the numerical results, the type 3 collar system was selected to realize the specimens for the tests (Fig. 12).

In particular, the wooden stock, made of new timber without any surface irregularity, has a rectangular cross-section, 160×200×500 mm size (Fig. 12a), with rounded off corners. The collars, made of S275 steel grade, are composed by 2 parts with lateral wings bolted to each other and both superior and inferior steel studs welded to the collar (Fig. 12b). Bolts are of 8.8 grade and both 8 mm and 12 mm diameters were used. The rubber layer was simply in contact with the collar, without any glue.

Specimens are labelled as indicated in Fig. 13.

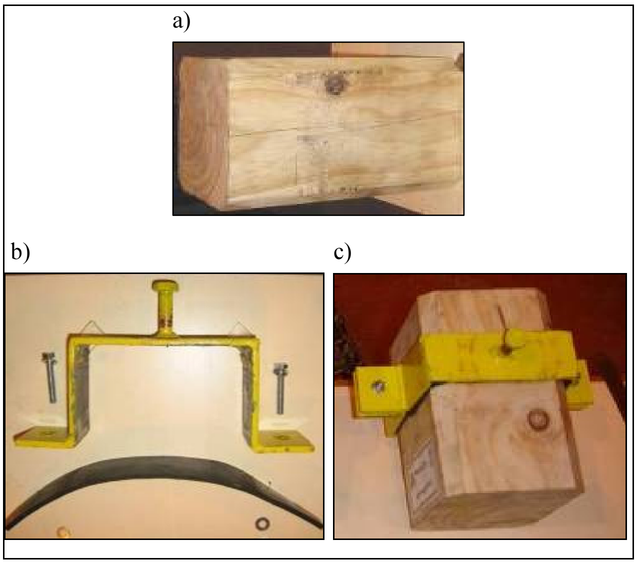


Fig. 12. The specimen used for the tests: a) rectangular shaped wooden stock; b) type 3 collar; c) assembled specimen

Legend

2 = Bolt numbers
SC = No glue
G = Rubber layer
(G: rubber; P: no rubber)
00 = Stiffness plate angle
12.5 = Bolt tightening (kN)
M1 = Type and number of the test (M: monotonic)

Fig. 13. Specimen label definition

A purposely designed steel frame, was realized as a support for the specimens (Fig. 14a): the collar is fixed to it by inserting the studs into carvings, any movement of studs inside the slots are hindered by means of ad hoc shaped clamping plates and bolts (Fig. 14b).

The used actuator (INSTRON) has a loading capacity of 250 kN in both tension and compression (Fig. 14c). Electric displacement transducers (LVDT), having a maximum stroke of 25 mm and an accuracy of 1×10^{-3} mm, were placed at the 4 corners of the specimen (Fig. 14d) by means of plastic arms, in order to measure relative stock-collar displacements. Both transducers and actuator were connected to an electronic device and to a PC, in order to allow data acquisition and recording.

For all tests, a quasi-static loading procedure was applied in displacement control, using a constant displacement velocity equal to 0.10 mm/sec. Therefore, the applied displacements were progressively increased through steps of 10 mm amplitude up to reach the loss of wood-rubber friction.

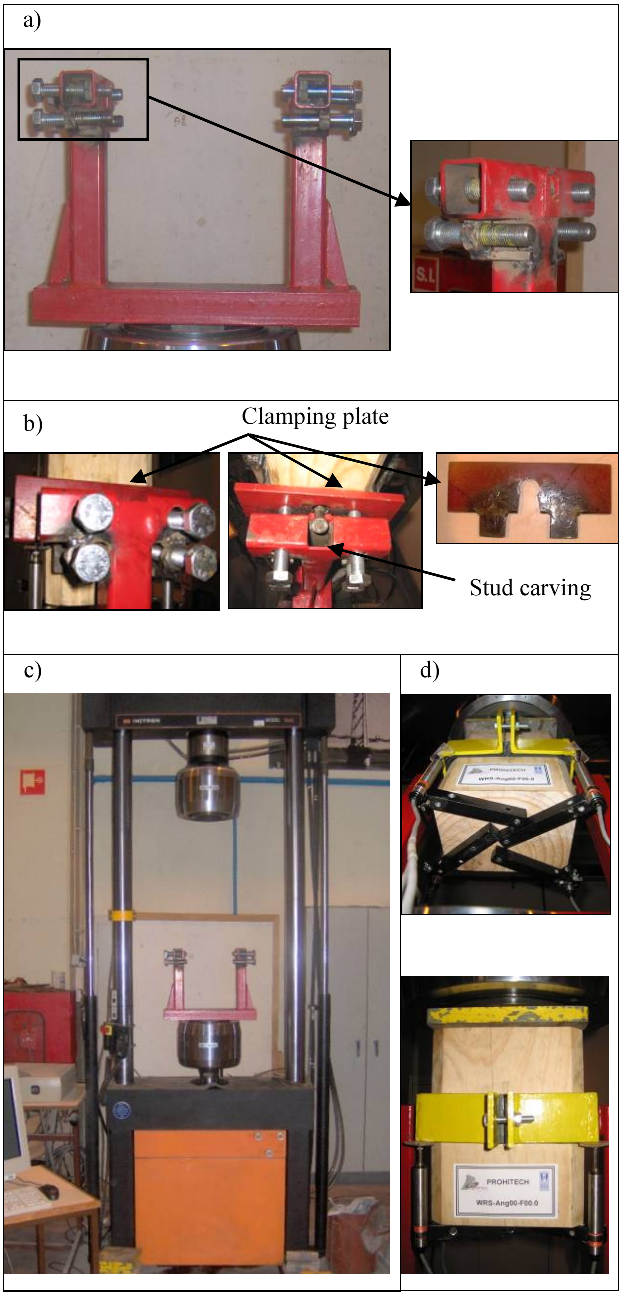


Fig. 14. Testing apparatus: a) steel supporting frame; b) specimen fitting; c) actuator; d) transducers location

4.2. Preliminary tests

First tests have evidenced a relevant rotation between the collar parts each other, as well as slipping at the collar-rubber layer interface, occurring at about 5% of maximum predicted load (Fig. 15). Therefore the system was upgraded: 1) the internal face of the collar has been equipped with two 5×3 mm edges, welded at both sides, in order to realize a mechanical barrier to the rubber slipping (Fig. 16a); 2) the connection between the collar parts was realized by means of two bolts instead of one at each couple of wings, in order to impede their relative rotations (Fig. 16b). The total tightening force $N_{s,t}$ is equal to 50 kN (12.5 kN at each bolt).

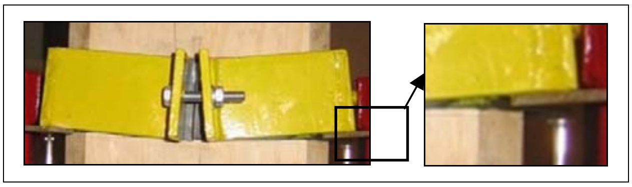


Fig. 15. Deformed configuration after preliminary tests

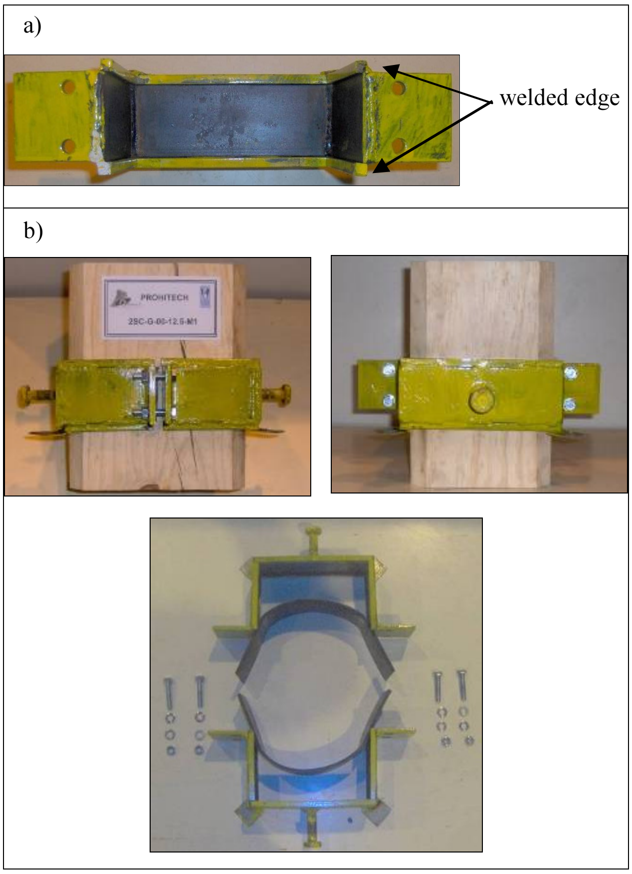


Fig. 16. Upgraded system after preliminary tests: a) welded edges; b) 2 bolts per wing

It is worth noticing that the welded edge does not come in contact with the timber stock, because the rubber layer is by 2 mm thicker than the edge.

The improved specimen was used for carrying out two tests. Results are plotted in Fig. 17 in terms of force (F)-slip(s) curves, relevant to each single transducers, together with the average curve.

In Fig. 18, the average curves and the theoretical one are compared. The ratio ($\bar{F}$) between the actual maximum applied force (F_{max}) and the maximum theoretical one (F_0) is also given.

The two specimens exhibit a very similar response. In particular, the first growing branch corresponds to the shear deformation of the rubber layer jutted out of the edge, the flat branch corresponds to the slipping at the collar-rubber layer interface. A great difference can be noticed as respect to the theoretical curve; in fact, the tested system shows both stiffness and strength about two and five times smaller as respect to the ideal one.

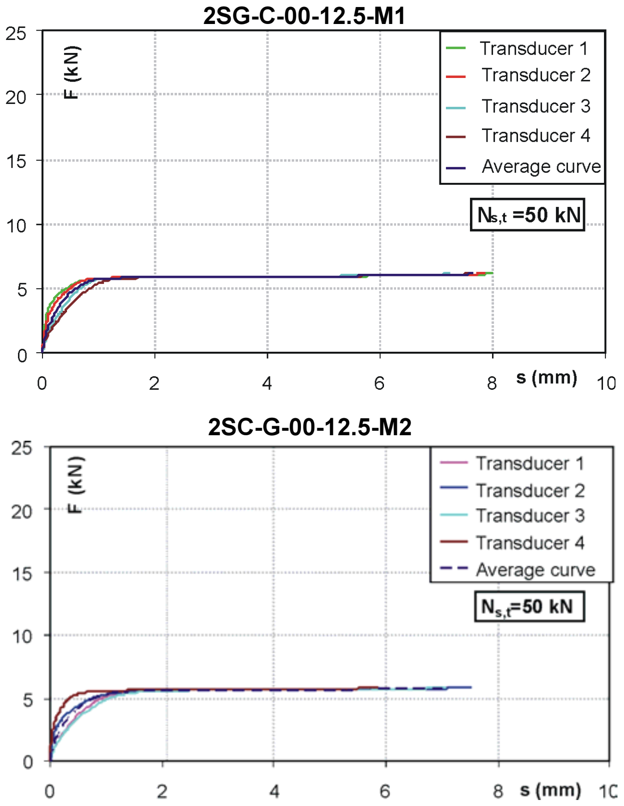


Fig. 17. Preliminary push-out tests: applied force (F) vs slip (s) curves

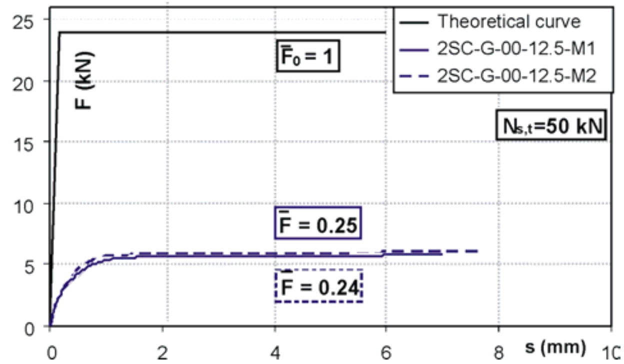


Fig. 18. Preliminary push-out tests: comparison between the average experimental curves and the theoretical one

4.3. The system improvements

With the purpose to improve both the stiffness and the strength of the connection system, the collars were provided with stiffening plates, 5 mm thick, welded at the wings, between the bolts, with a triangular shape and an inclination (α) of the hypotenuse equal to both 45° and 60° (Fig. 19).

Furthermore, the total tightening force Ns,t was doubled, being equal to 100 kN (25 kN at each bolt).

In all, 10 specimens were tested, 2 tests for each type of specimen; as indicated in Table 1, they definitively differ for the stiffening plate angle (45°–60°) and the bolt tightening (12.5–25 kN).

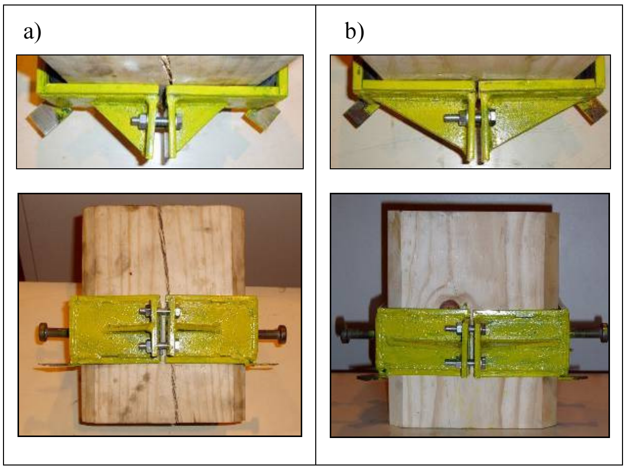


Fig. 19. Improved system by collar stiffening triangular plates: a) 45° angle; b) 60° angle

Table 1. Improved system: the tested specimens characteristics

Label	Number of specimens	α	$N_{s,t}$ [kN]
2SC-G-00-25-M1/M2	2	–	25 × 4 = 100
2SC-G-45-12.5-M1/M2	2	45°	12.5 × 4 = 50
2SC-G-45-25-M1/M2	2	45°	25 × 4 = 100
2SC-G-60-12.5-M1/M2	2	60°	12.5 × 4 = 50
2SC-G-60-25-M1/M2	2	60°	25 × 4 = 100

In Fig. 20 results are presented in terms of (F-s) curves, each curve being the average among the four transducers data; the theoretical reference curve is also given, for the sake of comparison. Furthermore, the comparison between the experimental responses of all the study cases is depicted in Fig. 21, considering the average values also between M1 and M2.

From Figs 20 and 21 it can be observed that:

- Under the same tightening, the stiffening plates produce an increment of strength (Table 2), which is larger for a wide stiffening plate angle (60°), on the contrary, no variation of the stiffness occurs.
- The bolt tightening increment induces an increase of both strength and stiffness, which is about 140% and 50%, respectively.

It is worth noticing that the increase of bolt tightening rather than the presence of stiffening plates allows for very significant improvements to both the strength and stiffness of the system.

Table 2. Improved system: the strength (ΔF) increment due to stiffening plates and bolt tightening

Bolt tightening $N_{s,t}$ [kN]	ΔF [%]	
	α	
	45°	60°
50	26	40
100	19	30

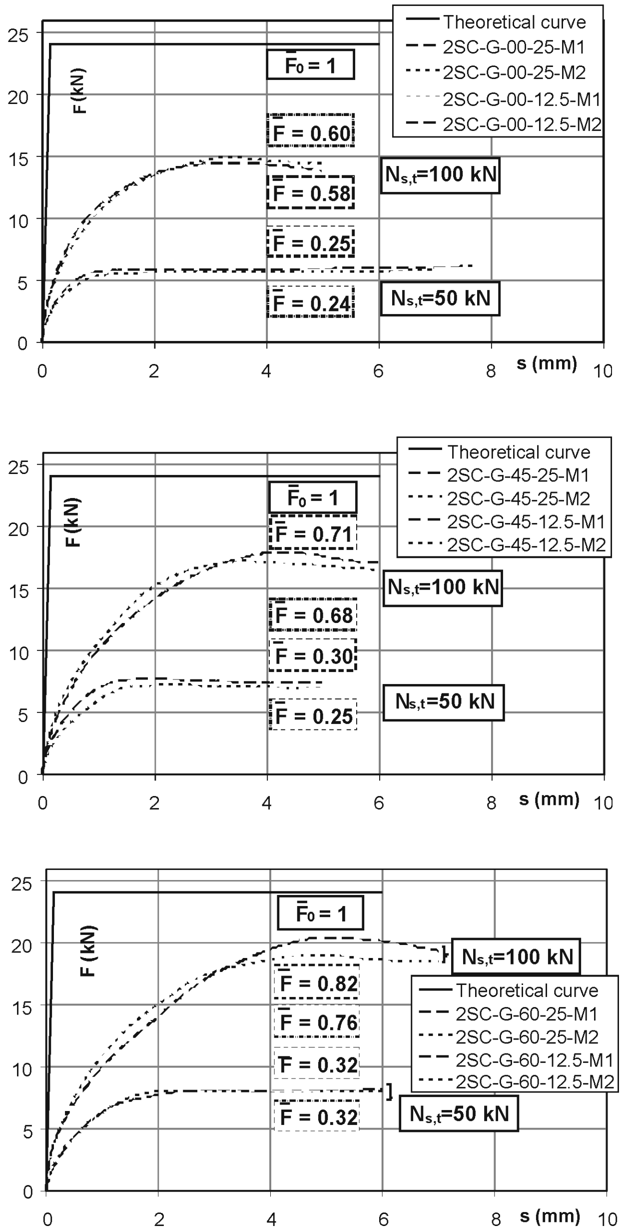


Fig. 20. Push-out tests of the improved systems: average and theoretical curves

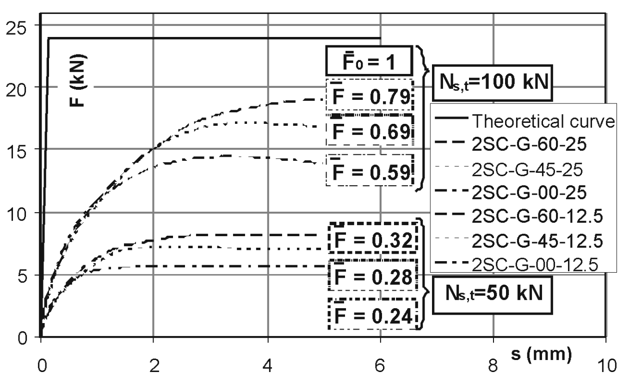
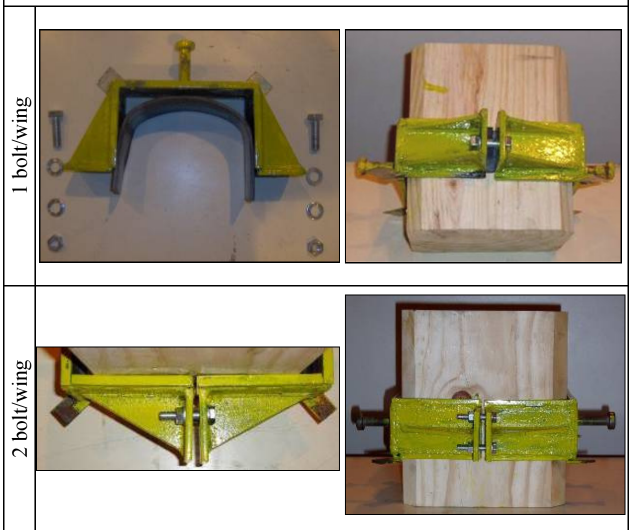


Fig. 21. Push out tests of the improved system: the effect of the stiffening plates

The beneficial effects of realizing a bolted connection between the collars, by two bolts per wing, instead of one, is evidenced in Fig. 22, where the (F-s) curves of two couples of specimens provided with one and two bolts per wing, respectively, with the same level of the total tightening force for each couple ($N_{s,t}$ = 50 kN and $N_{s,t}$ = 100 kN), are plotted. The tested specimens and their characteristics are represented in the same Fig. 22.

THE TESTED SPECIMENS



THE SPECIMENS CHARACTERISTICS

Label	Number of specimens	α	$N_{s,t}$ [kN]
1SC-G-60-25-M1/M2	2	60°	25 × 2 = 50
1SC-G-60-50-M1/2	2	60°	50 × 2 = 100
2SC-G-60-12.5-M1/M2	2	60°	12.5 × 4 = 50
2SC-G-60-25-M1/2	2	60°	25 × 4 = 100

THE PUSH OUT CURVES

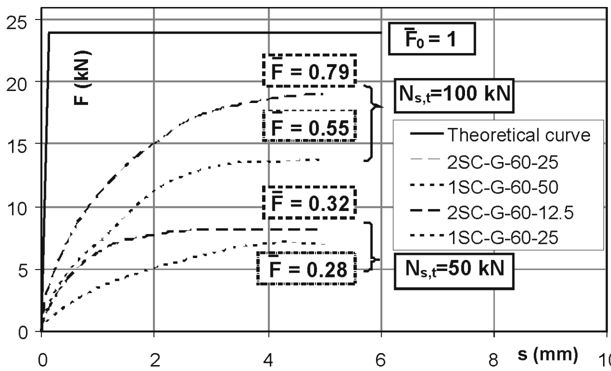


Fig. 22. Push out tests of the improved system: the effect of bolt number

As it is also apparent from Table 3, both strength and stiffness grow as far as the number of bolts and the total bolt tightening increase.

The last series of push-out tests were carried out on two specimens characterized by a two bolt connection per wing and 60° angle stiffening plates, with the collars directly in contact with the timber beams, no rubber layer being interposed. Therefore the lateral steel edges at the internal face of the collar were not adopted.

Table 3. Improved system: the strength (ΔF) and stiffness (ΔK) increments due to two bolts per wing

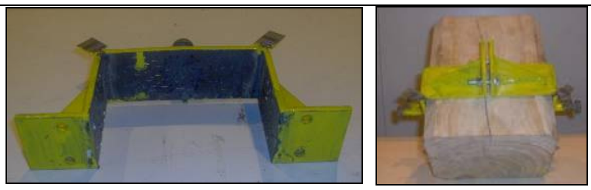
Bolt tightening $N_{s,t}$ [kN]	ΔF [%]	ΔK [%]
50	14	100
100	39	50

The steel-wood friction at the contact surface was upgraded by chiselling the collar at the internal side (Fig. 23). In the same Fig. 23 the specimens characteristics, in addition to the (F-s) push-out curves for the tested specimens with (G) and without (P) rubber layer, are presented for two levels of bolts tightening ($N_{s,t}$ = 50 kN and $N_{s,t}$ = 100 kN).

As it is apparent, the direct contact between the collar and the timber beam allows for a very good performance of the connection system, in terms of both strength and stiffness. In particular, for a total bolt tightening equal to 100 kN, the initial stiffness up to the design shear force is in a very good agreement with the theoretical one; furthermore the strength of the system is more then two times larger. A very slight damage of the wooden surface has occurred (Fig. 24).

The improvement of the system behaviour due to the steel-wood direct contact is evidenced in Table 4.

THE TESTED SPECIMENS



THE SPECIMENS CHARACTERISTICS

Label	Number of specimens	α	$N_{s,t}$ [kN]
2SC-P-60-12.5-M1/M2	2	60°	12.5 × 4 = 50
2SC-P-60-25-M1/2	2	60°	25 × 4 = 100

THE PUSH OUT CURVES

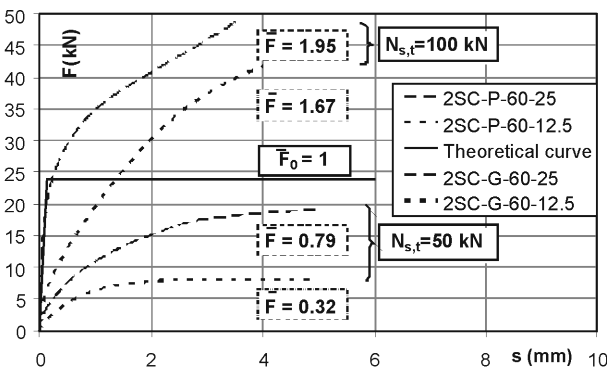


Fig 23. Push out tests of the improved system: the effect of the direct contact between the collar and the beam

It is worth noticing that the tests of the specimens without rubber layer were stopped before the collapse of the system was attained, in order to save the testing apparatus.

Table 4. Improved system: the strength (ΔF) and stiffness (ΔK) increments due to the steel-wood direct contact

Bolt tightening $N_{s,t}$ [kN]	ΔF [%]	ΔK [%]
50	420	100
100	156	400

Fig. 24. Surface damage of the specimens without rubber layer

5. Conclusive remarks

The present paper illustrates the push out monotonic tests, as a preliminary part of the experimental campaign, on the reversible innovative connection system for composite timber-steel-concrete-floor, consisting in a steel collar, astride the timber beam, with the interposition of a rubber layer. This is a very convenient and sometimes indispensable fact in case of retrofitting the existing ancient floor slabs.

The tests illustrated a rectangular system only, with new wood, which is not affected by irregularities at the surface. Preliminary tests of the basic system have highlighted some deficiencies of the connection, such as: 1) the bolt tightening induces a loss of contact between the rubber and the wood, therefore the contact surface has a smaller extension in respect of the ideal total one; this is due to a shape effect, most of the contact being concentrated at the section corner; 2) slipping occurs at the collar-rubber interface already at low forces; this is due to the fact that the rubber is simply in contact with the internal face of the collar, instead of vulcanized, because the vulcanization on a curved surface is a very costly operation, and the steel-rubber friction is not efficient enough to guarantee the solidarization.

Therefore some improvements to the basic system appeared to be necessary, in order to enhance both strength and stiffness of the connection. The upgrading solutions adopted are: to block the rubber movements by means of steel edges welded at the internal face of the collars at both sides and to stiffen the collars by welding triangular plates at the wings. The system performance has been improved, and the failure moved toward the rubber-wood interface, where the slipping occurred. Furthermore, the bolt tightening was increased, by using both higher bolt grades and two bolts per wings instead of one, in order to augment the friction resistance at the rubber-timber contact surface. In fact, the latter was not very large, the new timber surface being very smoothed. Although the results of push-out tests showed that all these improvements are very effective, nevertheless, the system is still quite far from reproducing ideal conditions. The last modification applied to the system consisted in eliminating the rubber layer, allowing the direct contact between the steel collar and the timber beam. In this case, in order to enhance the friction, the internal faces of the collar were chiselled. The tests results showed that the theoretical stiffness is achieved and the required strength exceeded, at the cost of a slight damage to the wooden surface.

With the purpose of achieving the system complete performance evaluation and optimization, further developments of the research activities include both numerical and experimental analyses. In particular, considering new timber beams with a rectangular-shape section, cyclic push-out tests on single connection devices and both monotonic and cyclic bending tests on composite timber-concrete beams, equipped with the collar connectors, are in progress. The same analyses are developing with ancient timber beams of circular shape. The final phase of the research activities will be devoted to test a full-scale wood-steel-concrete composite slab.

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The research activities are developed within the PROHITECH International Project "Earthquake Protection of Historical Buildings by Reversible Mixed Technologies", coordinated by F. M. Mazzolani.

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KOMPOZITINIŲ MEDŽIO, PLIENO IR BETONO PERDANGŲ STAČIAKAMPIŲ APKABINIŲ JUNGČIŲ EKSPERIMENTINIAI TYRIMAI: IŠSTŪMIMO BANDYMAI

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Santrauka

Pateikiami inovatyvios jungčių sistemos, taikomos medžio, plieno ir betono perdangose, eksperimentiniai tyrimai. Jungtį sudaro apkaba, sudaryta iš dviejų ar daugiau dalių. Ši jungtis apjuosia medinę siją, o atskiros jos dalys tarpusavyje sujungiamos varžtais. Tarp apkabos ir medžio paviršių dedamas gumos intarpas. Šlyties įtempius, atsirandančius medinės sijos ir gelžbetoninės perdangos sąlyčio zonoje, perima sparninės jungės arba prie apkabos viršutinės dalies privirintas plieno strypas. Straipsnyje pateikiami naujos jungčių sistemos kai kurių stačiakampio formos apkabų eksperimentinių išstūmimo bandymų rezultatai. Pateikti tyrimai yra dalis plačios eksperimentinių tyrimų programos, kuria siekiama atlikti naujos sistemos elgsenos analizę ir optimizavimą. Pirmiausia pateikiami preliminarūs skaitinės analizės rezultatai. Ši analizė skirta optimaliausioms geometrinėms charakteristikoms bei formoms parinkti. Paskui, priėmus atitinkamus geometrinių matmenų ir formų patikslinimus, atlikti išstūmimo eksperimentiniai tyrimai. Jungčių elgsena nagrinėta analizuojant jėgos ir praslydimo priklausomybes.

Reikšminiai žodžiai: kompozitinė medžio ir betono perdanga, apkabinė jungtis, išstūmimo eksperimentiniai tyrimai.

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